EGYPTIAN ACADEMIC JOURNAL OF

BIOLOGICAL SCIENCES

ENTOMOLOGY

A

ISSN
1687-8809

WWW.EAJBS.EG.NET

Vol. 16 No. 2 (2023)

Citation: *Egypt. Acad. J. Biolog. Sci. (A. Entomology) Vol. 16(2) pp.155-167 (2023)*
DOI: 10.21608/EAJBSA.2023.311332

Egypt. Acad. J. Biolog. Sci., 16(2):155-167(2023)

Egyptian Academic Journal of Biological Sciences
A. Entomology

ISSN 1687- 8809
http://eajbsa.journals.ekb.eg/

Seasonal Activities of *Lepidosaphes beckii* and Its Associated Natural Enemies in Response to Habitat Environment

Naglaa M. Youssef; Salma Kh. Ragab and Nabil M. Ghanim
Plant Protection Research Institute. Agricultural Research Centre, Dokki, Giza, Egypt
***E-mail:** salmakhiry1984@gmail.com

ARTICLE INFO
Article History
Received:23/4/2023
Accepted:24/6/2023
Available:28/6/2023

Keywords:
Lepidosaphes beckii, natural enemies ,*Aphytis lepidosaphes*, *Chilocorus bipustulatus*.

ABSTRACT

The purple scale, *Lepidosaphes beckii* (Newman) (Hemiptera: Diaspididae) is one of the most important armored scale insects infesting citrus trees in Egypt. The present study was conducted aiming to a better understand the seasonal activities of *L. beckii* and its associated natural enemies, *Aphytis lepidosaphes* Compere (Hymenoptera: Aphelinidae) and the predator, *Chilocorus bipustulatus* (L.) (Coleoptera: Coccinellidae) in response to habitat environment (host plant species and certain weather factors) during two successive years (2019 and 2020) in Dakahlia governorate, Egypt. The obtained results indicated that *L. beckii* is present in the orchards all around the year infesting leaves of navel orange, mandarin and lemon trees showing one to three peaks of activity yearly. *A. lepidosaphes* recorded one to two peaks of activity (as parasitism%) on *L. beckii* adults in navel orange, mandarin and lemon orchards; while *C. bipustulatus* exhibited one to three peaks (as predatism%) on the pest stage. *A. lepidosaphes* and *C. bipustulatus* act in density-dependent reactions; where statistical analysis showed that there were good synchronizations between *L. beckii* and populations of these natural enemies. *L. beckii* population was significantly higher in navel orange orchards followed by mandarin and lemon orchards, respectively. On the contrary, the activities of studied natural enemies were mostly higher in significant values in lemon orchards followed by mandarin and navel orange orchards, respectively. So, it can be concluded that the relatively low population levels of L. beckii in lemon orchard may be attributed to the relatively high activities of the recorded natural enemies, and vice versa. The daily temperature degrees had mostly high significant positive effects on the activities of *L. beckii* and both *A. lepidosaphes* and *C. bipustulatus*; while the daily means of relative humidity had mostly insignificant effects on them.

INTRODUCTION

Citrus species are considered the major fruit crops in Egypt because of its cultivated area (204095 Hectare), which produces about 4272886 metric tons, from which around 1.34 million tons are exported according to the Ministry of Agriculture (2016), Egypt ranking as the sixth biggest producer of orange throughout the world after Brazil, China, US, EU, and Mexico (Abobatta, 2018). Citrus trees are at risk of sustaining damage by scale insect infestations including armored (diaspidid) scales. Armored scales are economically the most important, by damage and numbers (Amouroux *et al*., 2017). It has

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long stylets (mouthparts) which reached six to eight times longer than its body tall. These insects can occur on leaves, twigs, branches, or trunks (the affected area looks like a fire burn) causing damage to trees by extracting vital fluids, resulting in yellow and fall-off leaves, reduction of fruit production (quality & quantity) and death of the plant. Armored scales (like other scale insects) get their name from the protective, shell-like covering that they form on themselves (Wawrzynski & Ascerno, 2009).

The purple scale, *Lepidosaphes beckii* (Newman) (Hemiptera: Diaspididae) is one of the most important armored scale insects infesting citrus trees in Egypt and many parts of throughout the tropical and subtropical regions (Danzig & Pellizzari, 1998, Magro & Hemptinne, 1999, Claps *et al*., 2001, Foldi, 2001, Draz *et al*. 2011, Moustafa, 2012, Belguendouz *et al*. (2015), Stathas *et al*., 2015, El-Husseini *et al*., 2018, Zaabta *et al*., 2020, Agagna *et al*., 2022 and Esmaeili *et al*., 2022). It is a polyphagous species; where, it had been reported almost on 176 genera (belonging to 83 families) of plants (Davidson & Miller, 1990, Aly, 2011 and Garcia *et al*., 2016). All stages of L. beckii are present in the orchards all around the year; so, it gives a sequent of overlapping generations (Fadamiro *et al*., 2008). There are one to four generations depending on climatic conditions (Davidson & Miller, 1990, Gill, 1997, De Villiers, 1998, Watson, 2002, Habib *et al*., 2009 and El-Amir *et al*., 2012).It is possible to control the insect biologically using natural enemies (Coutin, 1988). Many natural enemies associated with the scale insects are reported worldwide, such as the predatory insects belonging to the Orders of Coleoptera (coccinellids, nitidulids, tenebrionids), Neuroptera (chrysopids), Thysanoptera (phlaeothripids) and the hymenopterous parasitoids (aphelinids, cynipids, encyrtids, signiphorids) (Ben-Dov *et al*., 2014). The ectoparasitoid, *Aphytis lepidosaphes* Compere (Hymenoptera: Aphelinidae) and the predator, *Chilocorus bipustulatus* (L.) (Coleoptera: Coccinellidae) are the most important bio-agent for controlling *L. beckii* in different parts of the world (Metwally *et al*., 1993, Orphanides *et al*., 1996, Abou Hatab, 1999, Magro & Hemptinne, 1999, Abd-Allah *et al*., 2002, Moustafa, 2012, Stathas *et al*., 2015, EL-Amir *et al*., 2020 and Agagna *et al*., 2022). *L. beckii* was considered the fourth most important pest of Texas citrus, but now it is under complete biological control by *A. lepidosaphes* (Ben-Dov *et al*., 2014). This parasitoid is listed among the “successfully introduced classical biological control agents” against *L. beckii* in Israel, Cyprus, France, Greece, Spain and Italy (EPPO, 2014). According to Abd-Allah *et al*. (2002), *C. bipustulatus* is a promising biocontrol agent against *L. beckii* in citrus orchards.

Because of the small size of insects and the characteristics of their bodies, biological aspects of insects are depending on climatic factors especially temperature degrees and thermal fluctuations (Chown & Nicholson, 2004). According to Aly (2011), Draz *et al*. (2011), Moustafa (2012) and El-Amir *et al*. (2020), weather factors especially temperature degrees mainly determine the growth rate in *L. beckii*, the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus*. On another hand, synchronizations between insect pests and their natural enemies determine their efficacy as biological control agents against the pest (Ghanim, 2003). Some natural enemies associated with *L. beckii* (especially *A. lepidosaphes* and *C. bipustulatus*) were recorded acting in density-dependent reactions; where, there were synchronizations between *L. beckii* population and the activities of these natural enemies (Abd-Allah *et al*., 2002, Moustafa, 2012, El-Amir *et al*., 2020 and Agagna *et al*., 2022).According to Zappala *et al*. (2012), understanding the mechanisms of population differentiation of an insect is essential to determine the relationship between ecological factors and the population dynamics of the insect. This knowledge is an important step in integrated pest management. So, the present study was conducted aiming at a better understanding of the seasonal activities of *L. beckii* and its associated natural enemies (the parasitoid, *A. lepidosaphes* and the predator, *C.*

bipustulatus) in response to habitat environment (host plant species and certain weather factors). In addition to determining the relationships between the pest and the ecological factors (natural enemies and weather factors).

MATERIALS AND METHODS

The present study was carried out in three orchards cultivated with three host plant species [navel orange (*Citrus sinensis* L.), mandarin (*Citrus reticulata* Blanco) and lemon (*Citrus limon* (L.) (Family: Rutaceae)]. These orchards were located in the Experimental Farm of the Faculty of Agriculture, Mansoura University during two successive seasons (from the 1st of January 2019 till the 29th of December 2020).From each host plant orchard, six trees homogenous in size and age were selected and marked for the present study. Samples were collected biweekly during the two studied years. Each sample consisted of 120 leaves (20 leaves/tree) collected from the different cardinal directions (north, south, east & west) and the center of the trees (four leaves/direction or center). Leaves were covered with paper bags on the tree, pulled up, well tied and transferred to the laboratory for investigation.

To estimate the seasonal activities of *L. beckii* and its associated parasitoid and predator, the leaves of each tree were investigated on both surfaces under a stereo microscope of 40-100 times magnification force in the laboratory. Nymphs and adults of *L.beckii* were recorded as living, parasitized (with living parasitoid or emerged holes) and predated (as predator-damaged).To determine the parasitoid specie, each sample was maintained for two weeks in Petri dishes (10 cm in diameter), containing a piece of moistened cotton wool. The emerged parasitoids were collected and identified. In addition, predator individuals (eggs, larvae, or adults) who were observed in the field or on the collected leaves were identified and recorded.

The percentage of parasitism (Par.%) and predates (Pred.%) were calculated as follows:

$$\text{Par. or Pre.}\,\% = \frac{\text{par. or pred.}}{\text{L.} + \text{par. or pred.}} x100$$

Where, L., par. and pred. are the number of living, parasitized and predated *L. beckii* adults, respectively.

Daily averaged temperature degrees and relative humidity were selected among the available meteorological data of Dakahlia governorate. These data were obtained from the Central Laboratory for Agricultural Climate, Agricultural Research Center, and Ministry of Agriculture, during the period from the whole two years of 2019 and 2020. The daily records of each weather factor were calculated as bi-weekly means according to the dates of samples.The mean bi-weekly numbers of *L. beckii* (nymphs, adults and total of them), and the means of parasitism or predatism percentages were correlated with each weather factor. Also, the correlation coefficient values between bi-weekly mean numbers of living *L. beckii* adults and the means of parasitized or predated adults of the same scale to determine the synchronization between activities of natural enemies and the pest population. Multi regressions and explained variance were analyzed. In addition, the obtained data were analyzed by using one-way ANOVA followed by L.S.D (the least significant difference) at a probability level of 0.05. All statistical analyses were done by using the computer program of CoHort Software (2004).

RESULTS

1. Seasonal Activity of *L. beckii* in Relation To Host Plant Species:

Data illustrated in Figure (1) showed that *L. beckii* was recorded all over the year infesting leaves of navel orange, mandarin and lemon trees during 2019 and 2020 years. During 2019, nymphs showed only one distinct peak of activity on the three studied host plants; while the adult population showed only one distinct peak in navel orange and showed three peaks of activity in mandarin and lemon orchard. Therefore, the total population of *L. beckii* showed only one peak activity in navel orange and lemon orchards (which was recorded as 86.9 and 54.0 individuals/leaf on the 22nd of October) and showed two peaks of activity in the mandarin orchard; these peaks were recorded as 50.5 and 65.4 on the 18th of June and 22nd of October, respectively.

During 2020, nymphs and adults of *L. beckii* showed one peak of population in the navel orange orchard and showed two peaks in both mandarin and lemon orchards (Fig., 1). Therefore, the total population of this pest showed one distinct peak in navel orange orchard (recorded as 92.1individuals/leaf on the 6th of October) and showed two peaks in mandarin (recorded as 66.6 and 73.8 individuals/leaf on the 8th of September and 20th of October) and lemon orchards (recorded as 46.8 and 47.8 individuals/leaf on the 25th of August 17th of November).

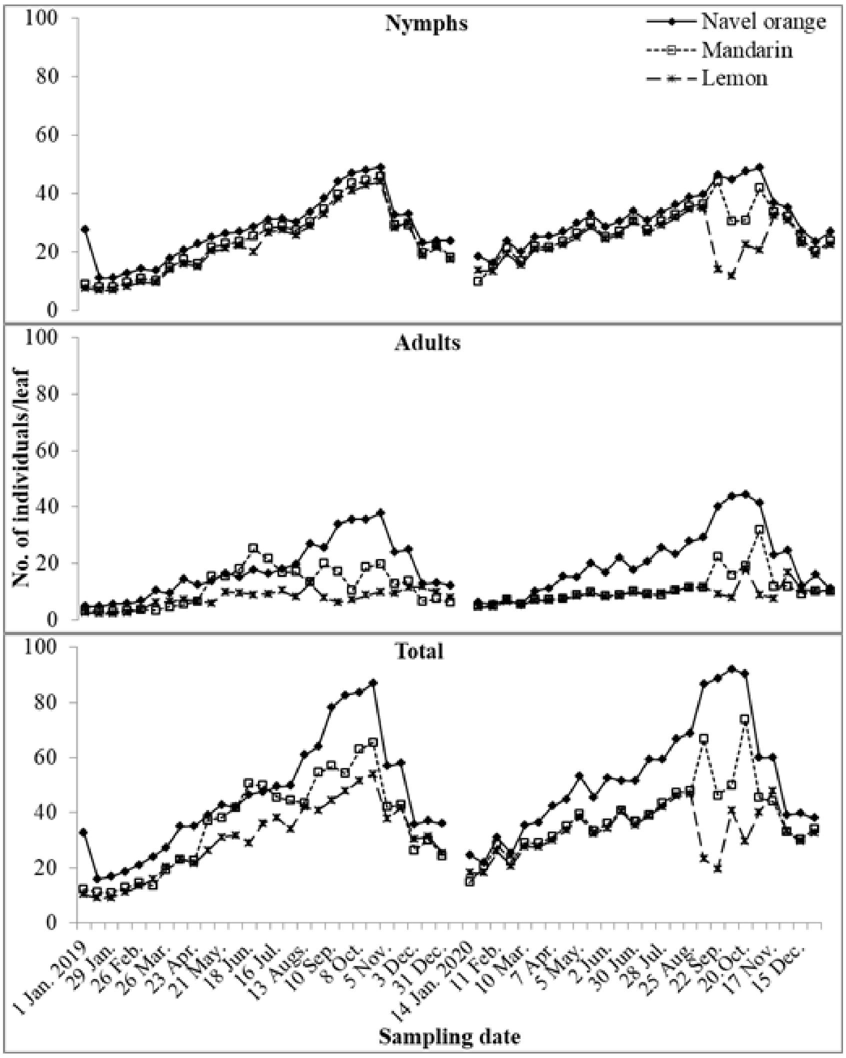

Fig. 1: Seasonal activity of *L. beckii* (recorded as nymphs, adults and a total of them) in navel orange, mandarin and lemon orchards during 2019/2020 years.

During the two years of the present study, statistical analysis showed that *L. beckii* infested navel orange leaves significantly more than mandarin followed by lemon leaves. As shown in Figure (2), the mean numbers of *L. beckii* (nymphs + adults) all over the year 2019 were as 44.3±0.8, 35.1±0.3 and 30.8±1.9 individuals/leaf in navel orange, mandarin and lemon orchards, respectively; while, during the year of 2020, these means reached 52.5±0.8, 38.4±0.9 and 32.6±0.3, respectively.

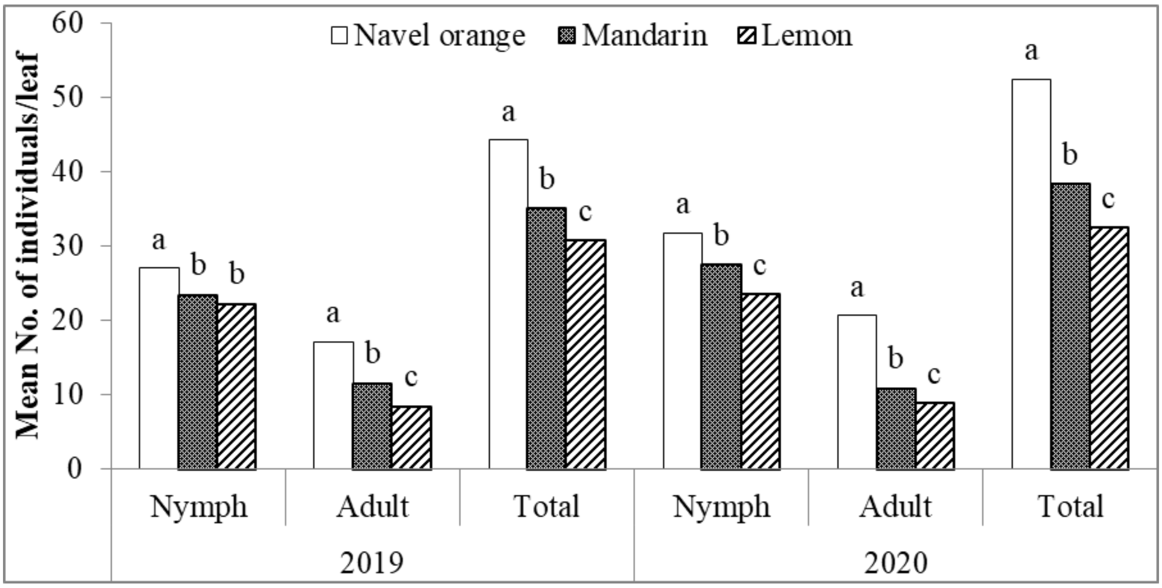

Fig. 2: Annual mean numbers of *L. beckii*/leaf (recorded as nymphs, adults and total of them) in navel orange, mandarin and lemon orchards during 2019/2020 years (Note: In each stage, columns had the same letter in each year did not differ at a significant of 5%).

2. Seasonal Activity of Natural Enemies Associated with *L. beckii* Adults in Relation to Host Plant Species:

The ectoparasitoid, *Aphytis lepidosaphes* Compere (Hymenoptera: Aphelinidae) and the predator, *Chilocorus bipustulatus* (L.) (Coleoptera: Coccinellidae) were recorded as natural enemies associated with *L. beckii* adults during the present study.

The activity of the parasitoid, *A. lepidosaphes* on *L. beckii* adult stage was measured as parasitism percentage (Fig., 3). During 2019, *A. lepidosaphes* showed two peaks of activity in navel orange and mandarin orchards; these peaks were recorded in navel orange orchards as 2.9 and 3.5% (on the 2nd of July and 19th of November), and recorded in the mandarin orchard as 1.9 and 5.5% (on the 9th of April and 22nd of October). The highest activity of *A. lepidosaphes* was recorded in the lemon orchard with only one distinct peak of activity (8.6%) on the 22nd of October. During 2020, *A. lepidosaphes* showed two peaks of activity in navel orange (2.7 and 5.0% on the 16th of June and 20th of October) and lemon orchards (5.4 and 19.9% on the 14th of July and 22nd of September); while it showed only one peak of activity in the mandarin orchard (16.0% on the 8th of September).

With respect to the activity of the predator *C. bipustulatus* in the adult stage of *L. beckii*, it was estimated as predatism percentages (Fig., 3). As shown in this figure, *C. bipustulatus* exhibited three and one peaks of activity in the navel orange orchard during 2019 (5.9, 5.8 and 5.9% on the 9th of April, 16th of July and 19th of November) and 2020 (11.0% on the 25th of August). In the mandarin orchard, *C. bipustulatus* exhibited two peaks of activity during 2019 (9.4 and 11.4% on the 26th of May and 24th of September) and 2020 (22.7 and 11.5% on the 25th of August and 3rd of November). *C. bipustulatus* exhibited one and two peaks of activity in the lemon orchard during the first (15.0% on the 8th of October) and second year (19.8 and 16.3% 25th of August and 20th of October).

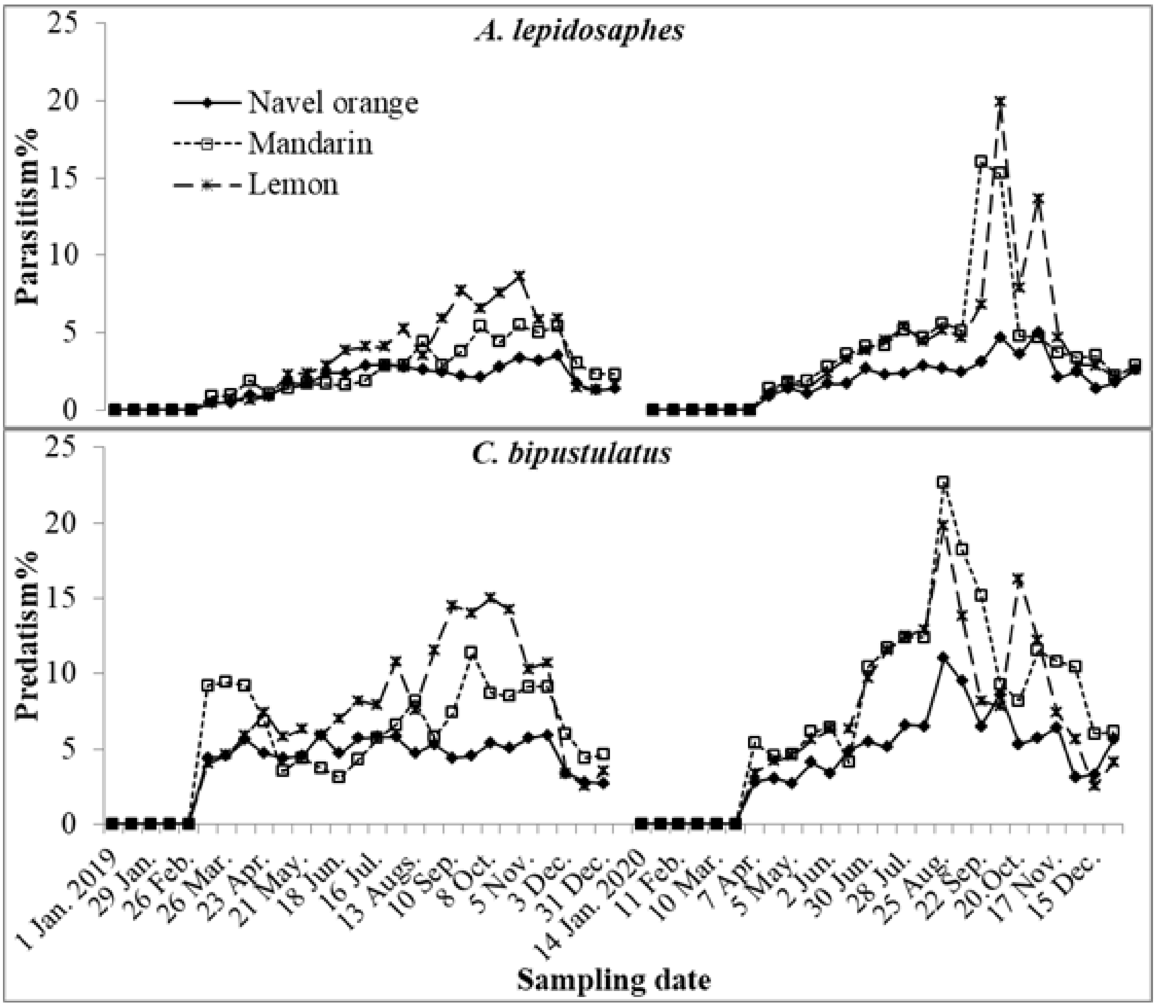

Fig. 3: Seasonal activity of the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus* on the adults of *L. beckii* in navel orange, mandarin and lemon orchards during 2019/2020 years**.**

As shown in Figure (4), the activities of the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus* in the adult stage of *L. beckii* were significantly higher in lemon orchard followed by mandarin and navel orange orchards, respectively. Where the mean parasitism percentages by *A. lepidosaphes* all over the year 2019 were 1.7±0.1, 2.3±0.1 and 3.1±0.3% in navel orange, mandarin and lemon orchards, respectively; while, during 2020, these means were 1.9±0.3, 3.7±0.1 and 3.9±0.3%, respectively. The mean predatism percentages by *C. bipustulatus* all over 2019 and 2020 years in the navel orange orchard were 3.9±0.3 and 4.3±0.4%; while, in the mandarin orchard were 5.5± 0.2 and7.6±1.4%, but in the lemon, orchard were 6.8±0.6 and 6.7± 0.3%, respectively.

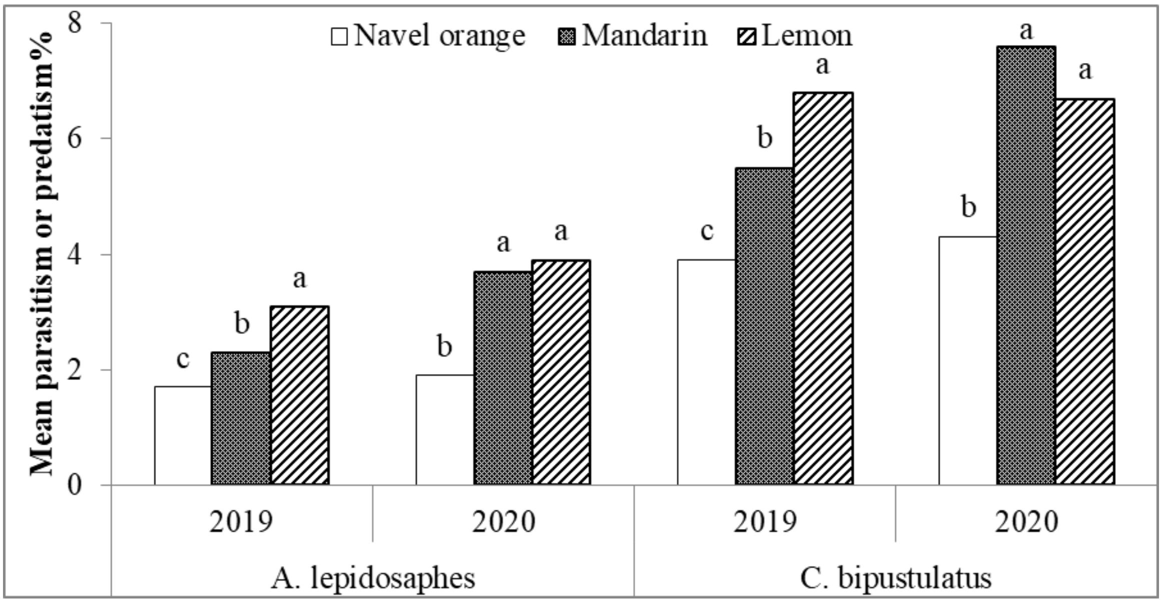

Fig. 4: Annual means of parasitism% (by *A. lepidosaphes*) and predatism% (by *C. bipustulatus*) on *L. beckii* adult stage in navel orange, mandarin and lemon orchards during 2019/2020 years (Note: In each natural enemy, columns had the same letter in each year did not differ at a significant of 5%).

3. Synchronization Between the Adult Stage of *L. beckii* and Its Associated Natural Enemies:

The statistical analysis represented in Table (1) showed that there is a very good synchronization between the total numbers of *L. beckii* adults and the numbers of parasitized or predated adults. Where, the correlation coefficient values between the total numbers of *L. beckii* adults and the numbers of parasitized (by *A. lepidosaphes*) or predated (by *C. bipustulatus*) adults in navel orange, mandarin and lemon orchards were mostly highly significant and ranged between 0.46 and 0.94 during 2019 and 2020 years.

Table 1: Correlation coefficient values between the adult population of *L. beckii* and the two recorded natural enemies (*A. lepidosaphes* and *C. bipustulatus*) in navel orange, mandarin and lemon orchards during 2019/2020 years

Host plant species	***A. lepidosaphes***		***C. bipustulatus***	
	2019	**2020**	**2019**	**2020**
Navel orange	0.94**	0.94**	0.69**	0.91**
Mandarin	0.73**	0.68**	0.75**	0.76**
Lemon	0.59**	0.46*	0.64**	0.57**

4. Response of *L. beckii* to the Daily Mean Temperature and Relative Humidity:

Data represented in Table (2) revealed that the daily means of temperature degrees had mostly highly significant positive effects on the activities of *L. beckii*. Where, the correlation coefficient values between the daily means of temperature degrees and *L. beckii* populations (nymphs, adults and total of them) during 2019 and 2020 in navel orange, mandarin and lemon orchards ranged between 0.42 and 0.90. On another hand, the daily means of relative humidity had mostly insignificant effects on *L. beckii* populations (nymphs, adults and total of them) during 2019 and 2020 in navel orange, mandarin and lemon orchards; where the correlation coefficient values between them ranged between 0.00 and 0.47 (some of them were negative).

Table 2: Correlation coefficient values between *L. beckii* (recorded as nymphs, adults and the total of them) and certain weather factors (daily means of temperature degrees and relative humidity) in navel orange, mandarin and lemon orchards during 2019/2020 years

Weather factor	**Insect stage**	**Navel orange**		**Mandarin**		**Lemon**	
		2019	**2020**	**2019**	**2020**	**2019**	**2020**
Temperature degrees	Nymphs	0.72**	0.82**	0.79**	0.83**	0.77**	0.49*
	Adults	0.72**	0.81**	0.90**	0.52**	0.64**	0.46*
	Total	0.73**	0.82**	0.89**	0.74**	0.42*	0.54**
Relative humidity	Nymphs	0.40*	0.05^{ns}	0.44*	-0.01^{ns}	0.45*	-0.25^{ns}
	Adults	0.47*	0.00^{ns}	0.11^{ns}	0.17^{ns}	0.20^{ns}	0.00^{ns}
	Total	0.44*	0.02^{ns}	0.34^{ns}	0.07^{ns}	0.42*	-0.19^{ns}

5. Response of the Recorded Natural Enemies (*A. lepidosaphes* and *C. bipustulatus*) to the Daily Mean Temperature and Relative Humidity:

As was reported on *L. beckii*, the daily means of temperature degrees had mostly high significant positive effects on the activities of the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus* (which was associated with the adults of *L. beckii*). Where, the correlation coefficient values between the daily means of temperature degrees and natural enemies (*A. lepidosaphes* and *C. bipustulatus*) during 2019 and 2020 in navel orange, mandarin and lemon orchards ranged between 0.44 and 0.84. On another hand, the daily means of relative humidity had mostly insignificant effects on the activities of *A. lepidosaphes* and *C. bipustulatus* during 2019 and 2020 in navel orange, mandarin and lemon orchards; where, the correlation coefficient values between them ranged between 0.05 and 0.47 (Table, 3).

Table 3: Correlation coefficient values between the activities of two recorded natural enemies (*A. lepidosaphes* and *C. bipustulatus*) and certain weather factors (daily means of temperature degrees and relative humidity) in navel orange, mandarin and lemon orchards during 2019/2020 years

Weather factor	**Natural enemy**	**Navel orange**		**Mandarin**		**Lemon**	
		2019	**2020**	**2019**	**2020**	**2019**	**2020**
Temperature degrees	*A. lepidosaphes*	0.84**	0.76**	0.61**	0.69**	0.76**	0.64**
	C. bipustulatus	0.78**	0.80**	0.44*	0.77**	0.78**	0.83**
Relative humidity	*A. lepidosaphes*	0.29^{ns}	0.05^{ns}	0.47*	0.09^{ns}	0.46*	0.12^{ns}
	C. bipustulatus	0.07^{ns}	0.06^{ns}	0.28^{ns}	0.09^{ns}	0.34^{ns}	0.03^{ns}

6. Combined Effect of Certain Weather Factors and Natural Enemies on *L. beckii* Adult Population in Relation to Host Plant Species:

The combined effect of weather factors (mean temperature degrees and relative humidity) and natural enemies (the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus*) on the adult population of *L. beckii* were statistically estimated. The mathematical relationships between the adult population of *L. beckii* each of temperature degrees (T.), relative humidity (RH), *A. lepidosaphes* (as parasitism%, Par.) and *C. bipustulatus* (as predatism%, Pred.) are represented as follow:

In Navel Orange Orchard:

During 2019:

No. of adults = -26.20 + 0.48 T. + 0.50 RH + 3.54 Par. + 0.17 Pred. (R^2 = 0.72)

During 2020:

No. of adults = -12.80 + 0.75 T. + 0.12 RH + 4.66 Par. + 0.14 Pred. (R^2 = 0.84)

In Mandarin Orchard:

During 2019:

No. of adults = -9.22 + 1.01 T. – 0.02 RH + 0.71 Par. - 0.56 Pred. (R^2 = 0.86)

During 2020:

No. of adults = -16.60 + 0.61 T. + 0.25 RH + 0.54 Par. - 0.29 Pred. (R^2 = 0.46)

In Lemon Orchard:

During 2019:

No. of adults = -4.05 + 0.32 T. + 0.08 RH - 0.32 Par. + 0.14 Pred. (R^2 = 0.44)

During 2020:

No. of adults = -2.55 + 0.33 T. + 0.08 RH - 0.13 Par. + 0.02 Pred. (R^2 = 0.25)

As shown in the previous relationships the total effects of temperature degrees, relative humidity, *A. lepidosaphes* and *C. bipustulatus* in the navel orange orchard represented 72 and 84% of the total factors affecting *L. beckii* adult population during 2019 and 2020 years. In the mandarin orchard, the combined effect of these factors was represented by 86 and 46%; while, in the lemon orchard, this combined effect reached 44 and 25% of the total factors affecting *L. beckii* adult population during 2019 and 2020 years.

DISCUSSION

The purple scale, *L. beckii* is present in the orchards all around the year, giving sequent overlapping generations (Fadamiro *et al*., 2008). Also, the present study revealed that *L. beckii* was recorded all over the year infesting leaves of navel orange, mandarin and lemon trees showing one to three peaks of activity during 2019 and 2020 years. These results are partially in agreement with those obtained by Aly (2011), Draz *et al*. (2011), Belguendouz *et al*. (2015), Zaabta *et al*. (2020), Agagna *et al*. (2022) and Esmaeili *et al*. (2022); they reported that *L. beckii* exhibited three peaks of activity in mango and citrus orchards in Egypt, Algeria and Iran. Also, in Egypt, Moustafa (2012) and El-Amir *et al*. (2020) reported that *L. beckii* exhibited one to two peaks of activity in citrus and apple orchards. De Villiers (1998), Watson (2002), Habib *et al*. (2009) and El-Amir *et al*. (2012) showed that *L. beckii* has up to 4 generations per year depending on environmental conditions. In California, Gill (1997) mentioned that there are three to four overlapping generations yearly. Benassy *et al*. (1975) added that the number of peaks varies according to the climatic conditions of the studied area, and it was observed that the lowest number of generations is in cold countries, especially in winter.

According to Abdel-Fattah & El-Saadany (1978), Hafez *et al*. (1987), Moustafa (2012), Stathas *et al*. (2015), EL-Amir *et al*. (2020) and Agagna *et al*. (2022), *A. lepidosaphes* is the most common parasitoid on *L. beckii*. In the present study, *A. lepidosaphes* recorded one to two peaks of activity on *L. beckii* adults infesting leaves of navel orange, mandarin and lemon trees. These results agreed with the result of Moustafa (2012) and El-Amir *et al*. (2020); they reported that the parasitoid, *A. lepidosaphes* exhibited one to two peaks of activity on *L. beckii* infesting citrus and apple orchards in Egypt. Also, the present result is near to the results of Stathas *et al*. (2015) and Zaabta *et al*. (2020); they recorded two to three peaks of *A. lepidosaphes* activity on *L. beckii* infesting citrus orchards in Greece and Algeria. According to Aly (2011), there was no parasitism by *A. lepidosaphes* on *L. beckii* during the months of January, February and March. These findings support the present study; which revealed that there was no record of parasitism percentages on *L. beckii* by *A. lepidosaphes* during these months, especially during the second year.

The coccinellid, *C. bipustulatus* was the most dominant predator associated with *L. beckii* and it seems to be one of the most mortality factors for *L. beckii* (Metwally *et al*., 1993, Orphanides *et al*., 1996, Abou Hatab, 1999, Magro & Hemptinne, 1999, Abd-Allah *et al*., 2002, Moustafa, 2012 and EL-Amir *et al*., 2020). During the present study, *C. bipustulatus* exhibited one to three peaks of activity in navel orange, mandarin and lemon orchards. These findings are in agreement with Moustafa (2012) and El-Amir *et al*. (2020); they reported that the predator, *C. bipustulatus* exhibited one to two peaks of activity on *L. beckii* infesting citrus and apple orchards in Egypt. Abd-Allah *et al*. (2002) reported that *C. bipustulatus* showed two to three peaks of activity in citrus orchards. In Greece, Stathas *et al*. (2015) reported that *C. bipustulatus* showed two periods of activity every year in citrus orchards infested with *L. beckii*.

Statistical analysis of the present study showed that there were good synchronizations between *L. beckii* and each of the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus* populations. So, it could be concluded that *A. lepidosaphes* and *C. bipustulatus* act in density-dependent reactions. Also, Moustafa (2012) recorded good synchronizations between *L. beckii* and each of *A. lepidosaphes* and *C. bipustulatus* populations in citrus orchards. El-Amir *et al*. (2020) recorded a good synchronization between *L. beckii* and *A. lepidosaphes* and reverse synchronization between *L. beckii* and *C. bipustulatus*. With respect to Agagna *et al*. (2022); they noticed that the development of *A. lepidosaphes* was in perfect synchronization with the availability of its host *L. beckii*. In the study of Abd-Allah *et al*. (2002) there was a good visual synchronization between *L. beckii* and *C. bipustulatus* populations.

According to Belguendouz *et al*. (2015), there were observed differences in the abundances between *L. beckii* populations in orange and lemon orchards at all the evolutionary stages of the pest. Where *L. beckii* populations were higher on orange trees than on lemon trees. These findings support the present study; which showed that there were differences in the activities of *L. beckii* and its associated natural enemies in navel oranges, mandarin and lemons orchards. Where, *L. beckii* population was significantly higher in navel orange orchards followed by mandarin and lemon orchards, respectively. On the contrary, the activities of natural enemies (the parasitoid, *A. lepidosaphes* and the predator, *C. bipustulatus*) were mostly higher in significant values in lemon orchards followed by mandarin and navel orange orchards, respectively. So, it can be concluded that the relatively low population levels of *L. beckii* in a lemon orchard may be attributed to the relatively high activities of the recorded natural enemies, and vice versa, the relatively high population levels of *L. beckii* in an orange orchard may be attributed to the relatively low activities of the recorded natural enemies. This theoretical assumption may be reinforced by a study by Ghanim (2003); who mentioned that up to 90% of the predated scale insects (*Ceroplastes floridensis* Comstock and *Pulvinaria psidii* (Maskell)) were failing down from the plants after predation by *C. bipustulatus*. This study showed that predators (especially *C. bipustulatus*) have a significant role in reducing the number of scale insects, but this role is generality not clear (especially in plant samples that were used in the present study).

The present study showed that the daily temperature degrees had mostly high significant positive effects on the activities of *L. beckii* and both of its parasitoid, *A. lepidosaphes* and its predator, *C. bipustulatus*; while the daily means of relative humidity had mostly insignificant effects on them. These findings are in agreement with Aly (2011); who reported that the daily temperature degrees had significant effects on the activities of *L. beckii* and *A. lepidosaphes*; while relative humidity had no significant effects on them. Moustafa (2012) reported that the effect of temperature degrees on *L. beckii* population was relatively higher (highly significant) than the effect of relative humidity (significant).

Also, Draz *et al*. (2011) recorded positive strong correlations between daily temperature degrees and *L. beckii* population. El-Amir *et al*. (2020) found the adverse effect of daily temperature degrees (especially maximum temperatures) on *L. beckii* population infesting apple orchard; while the effect of relative humidity was insignificant. From the study of El-Amir *et al*. (2020), it can be observed that there was a positive correlation between the population activity of *C. bipustulatus* and temperature degrees; while the contrary was observed with relative humidity.

The differences between the present study and any of the other studies may be due to the variation of the studied host plant species, climatic conditions in the different areas of studies, the cultivated plants in areas close to the studied host plant, agricultural practices in each studied region and/or personal differences between the researchers.

CONCLUSION

The purple scale, *L. beckii* is present in the orchards all around the year infesting leaves of navel orange, mandarin and lemon trees showing one to three peaks of activity yearly. *A. lepidosaphes* and *C. bipustulatus* could be considered promising effective biological control agents against *L. beckii* as they act in density-dependent reactions. Host plants showed a significant effect on the activities of *L. beckii* and its natural enemies. Daily temperature degrees were the main driver for the activities of *L. beckii* and its natural enemies; while daily mean relative humidity had no significant effect on them.

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